IN-SITU ANALYSIS OF EUROPA ICES BY MELTING PROBES

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Purpose and Scope

- How best to access (for sampling/analysis) the material embedded in or underneath icy layers on the surface of. e.g. Europa ?
- One possible technique for ices: penetrate by melting, with small probes which do not require a heavy and complicated drilling equipment
- In principle, even tens of km could be penetrated with given time and energy
- Would allow in-situ analysis.
- “Shallow melting” (~meters) vaporize ice/volatiles, to be analysed eg with GCMS

Melting Probes for Planetary Exploration

- Heritage: terrestrial applications (polar ice sheets)
- Europa Icy Shell
- Mars Polar Caps
- other icy Satellites ...

Challenges for Planetary Applications

- Mass and Power requirements
- Lander and Deployment device required
- Vacuum (→ sublimation instead melting?)
- Very low ambient temperatures (→ power)
- Lower gravity (no principal issue)
- Communications (difficult through dirty/salty ice)
- In-situ instrumentation

Efficiency (mass, energy)

- Energy by melting (300 MJ/$m^{3)}$ higher than cutting ice (drilling ~1-20 MJ/m^3)), but this does not include transmission losses and the energy for compacting the cuttings and transportation to and discharge at the surface – increases rapidly with depth!
- Mass of drill for planetary Landers: ~4 kg to reach 20 cm (Philae), ~20 kg to reach 2m (ExoMars)
- Melting probes in ice more efficient for depths > few dm, certainly > 2 m

Principles of melting through ice

To proceed by l, ***at least*** the energy

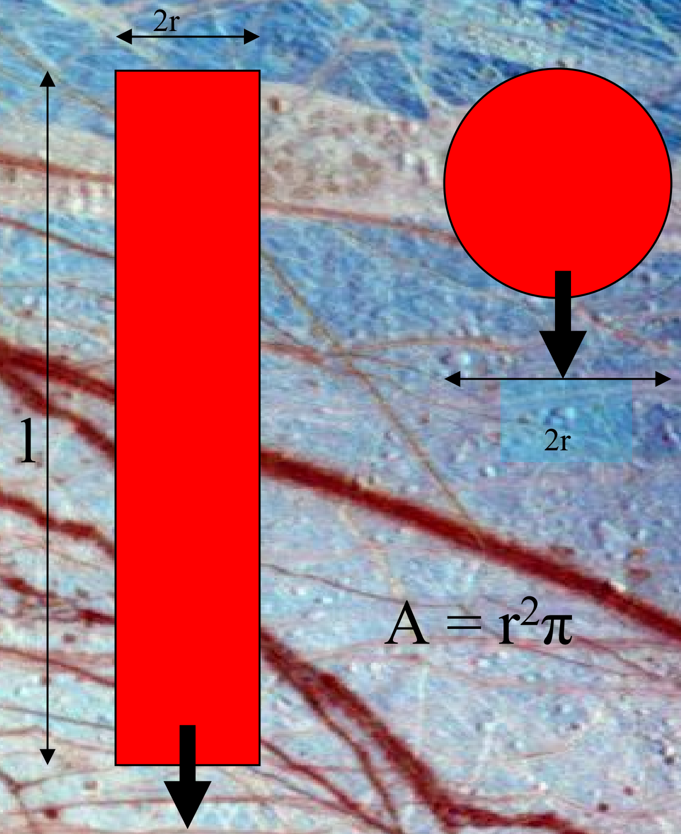
$$\Delta W = Al\rho\,[c_p(t_F - t) + L_v]$$

must be expedited. If the heating power is P, then the melting velocity is

$$\nu = lP / \Delta W = P / A\rho\,[c_p(t_F - t) + L_v]$$

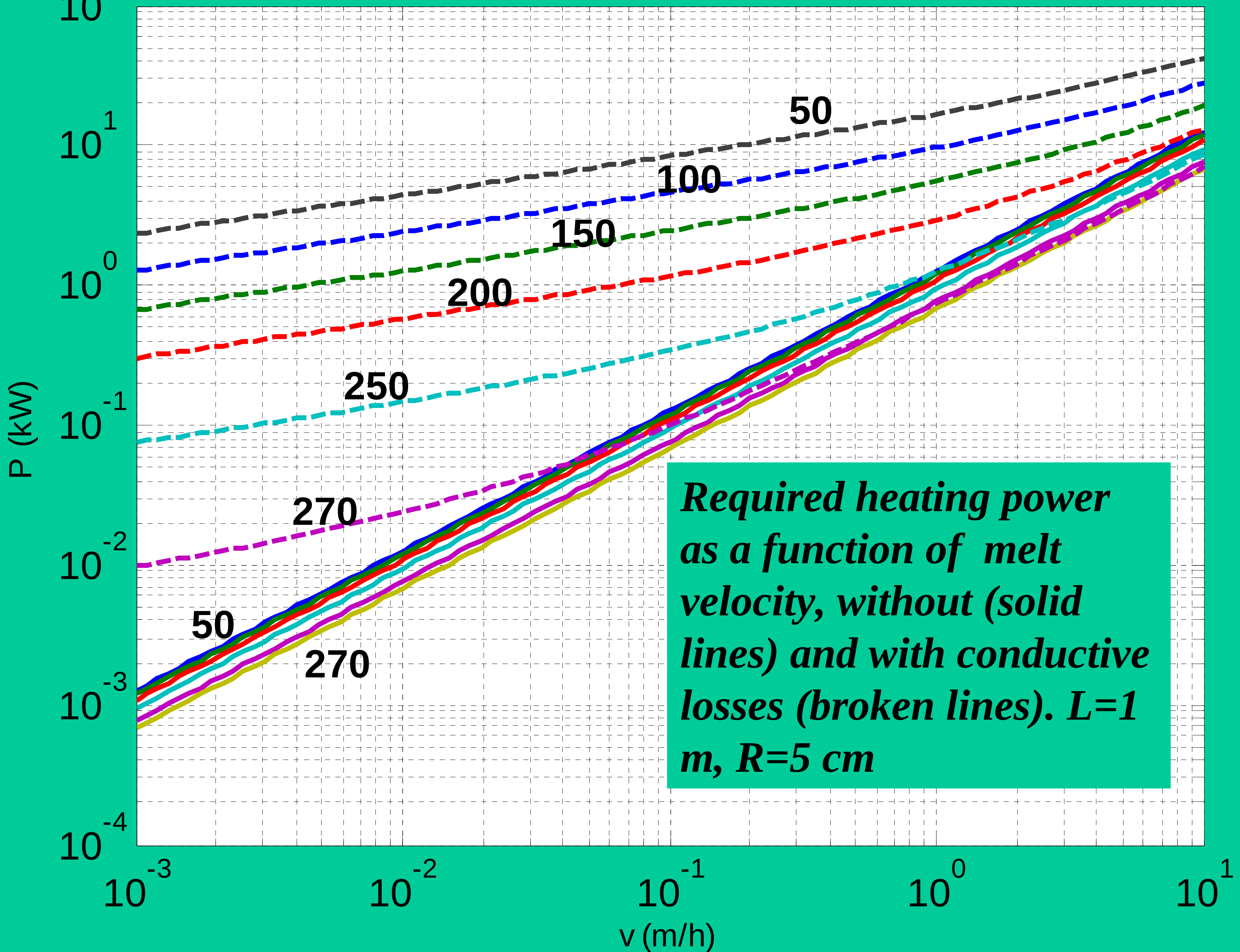
where

- A: cross section
- l: length
- c_p: specific heat capacity of ice (2 kJ / kgK)
- ρ: density of ice (920 kg / m^3)
- L_V: heat of fusion/sublimation of ice (334 kJ / kg ... 2800 kJ / kg)
- t_F: melting/sublimation temperature
- t: ice temperature

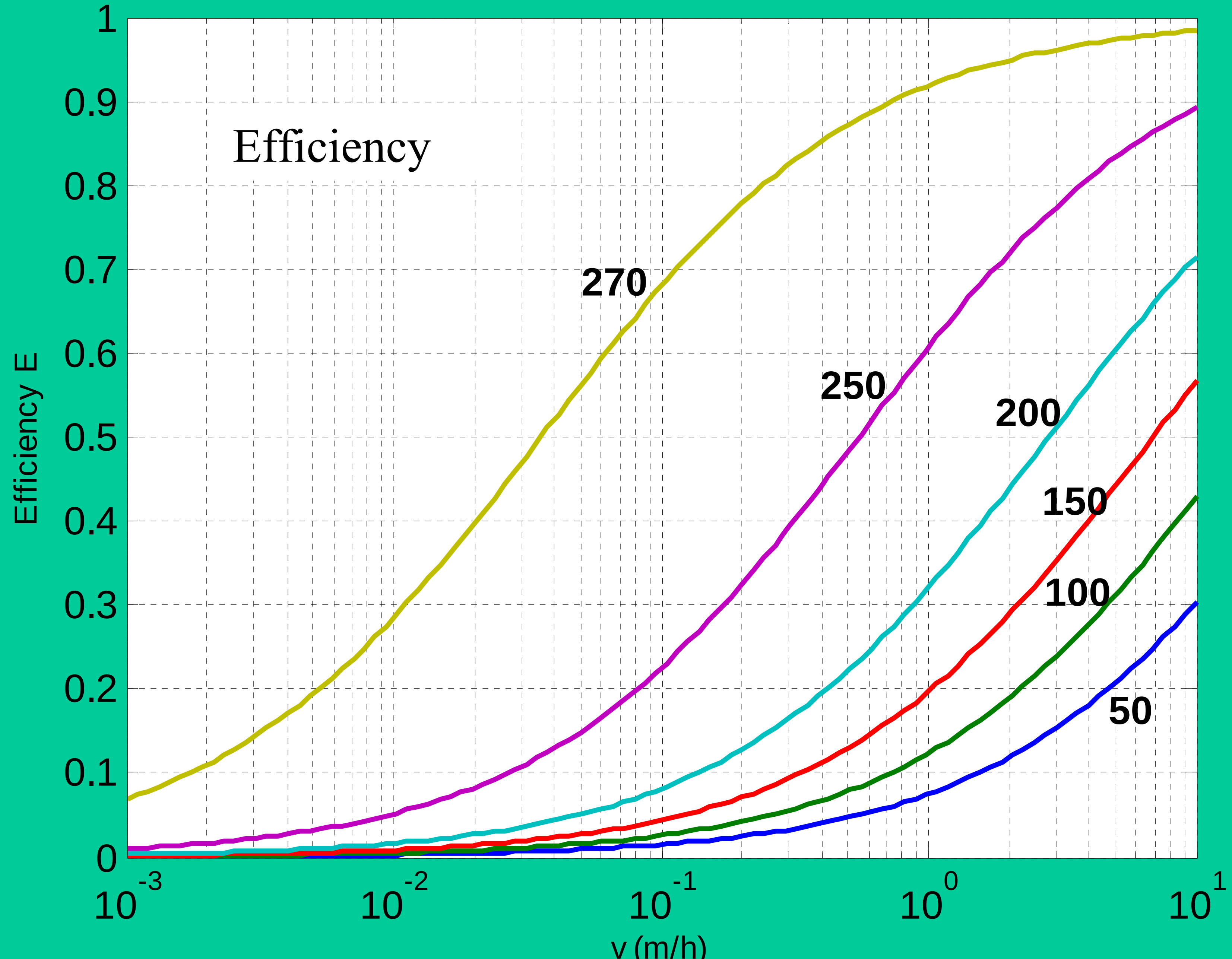


$A = r^2\pi$

Conclusion: small cross-section A!

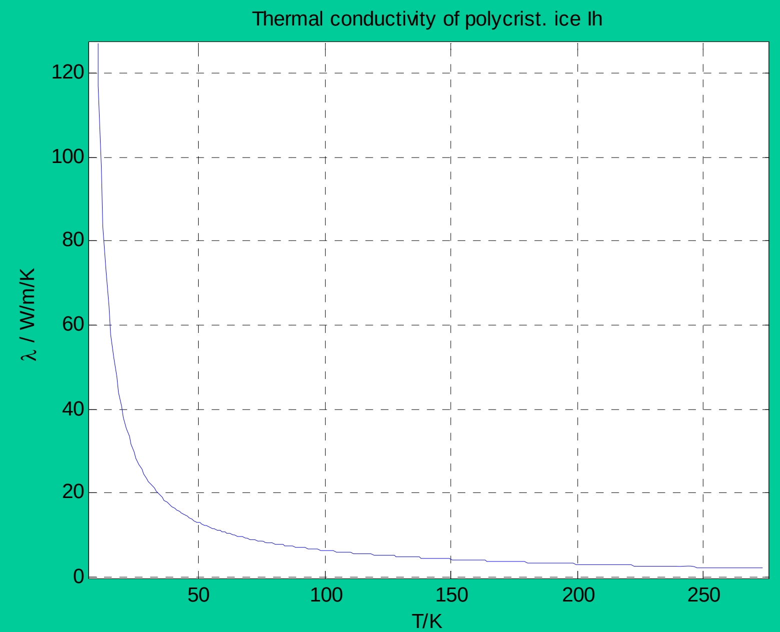


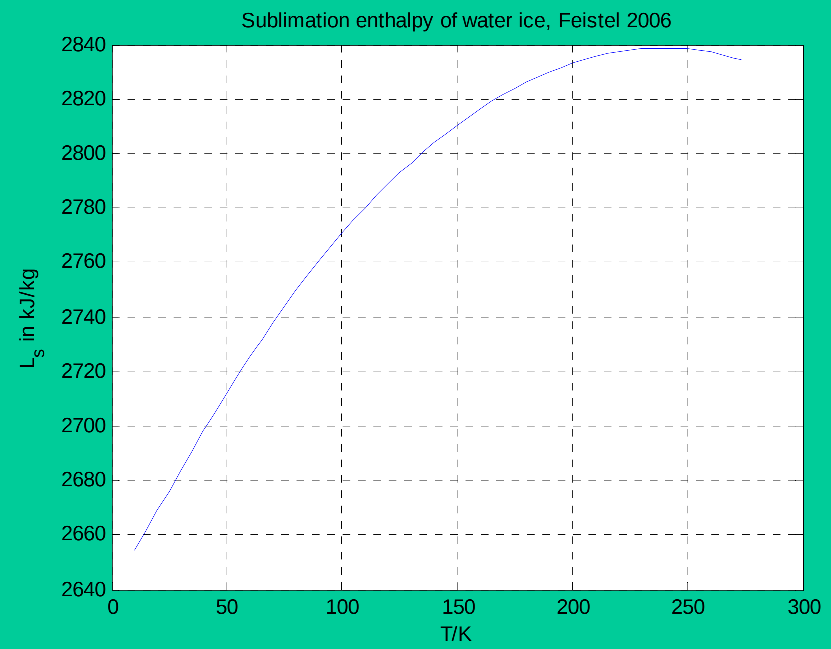
Required heating power as a function of melt velocity, without (solid lines) and with conductive losses (broken lines). L=1 m, R=5 cm

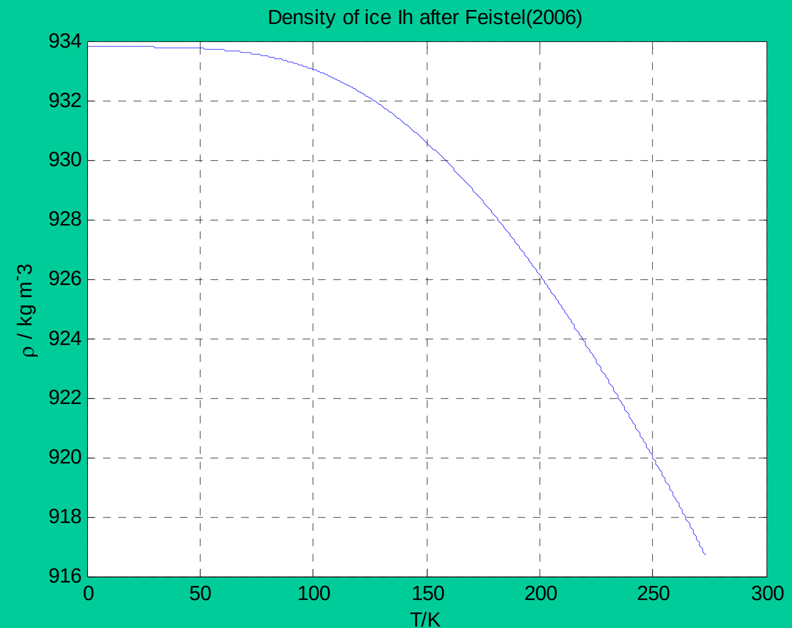


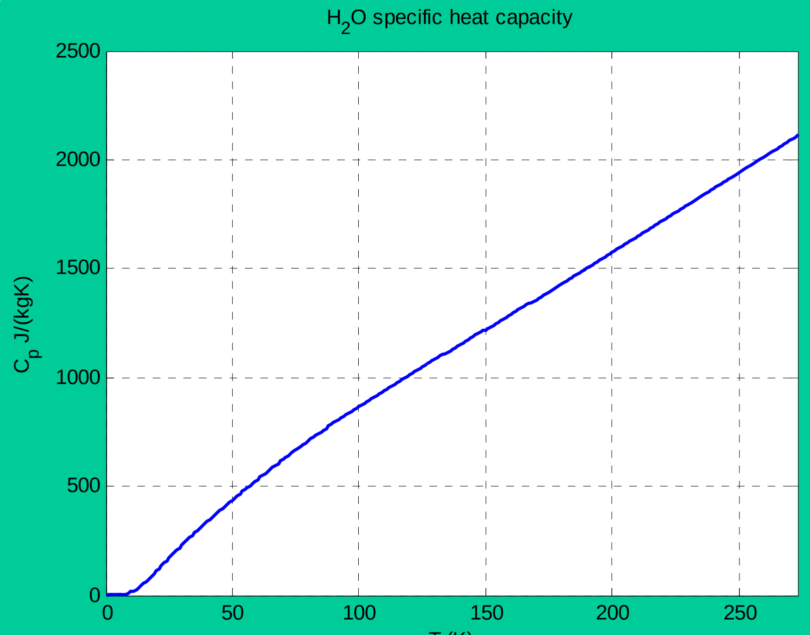
Efficiency
270
250
200
150
100
50
Efficiency E
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
v (m/h)

Ice thermophysical properties









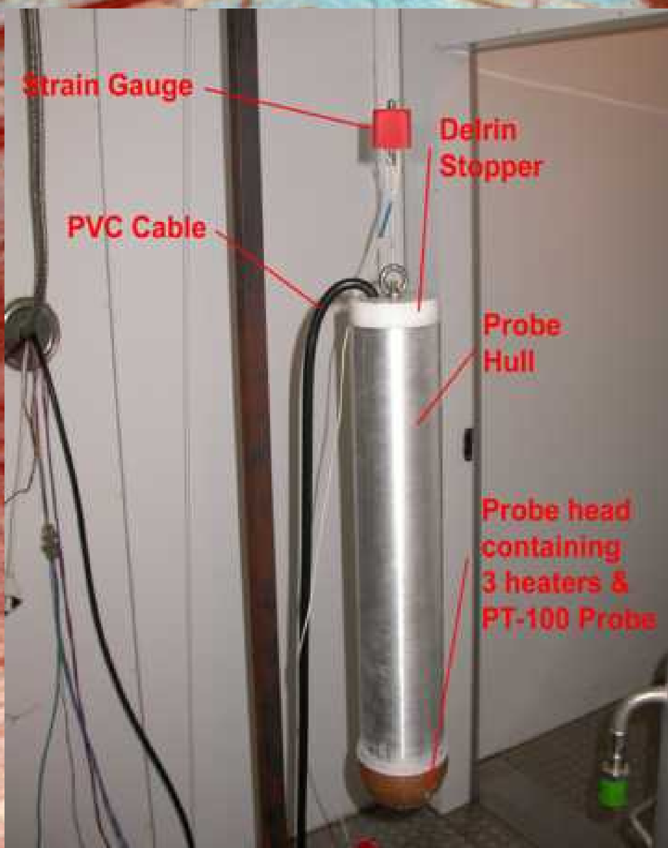
Ices other than water

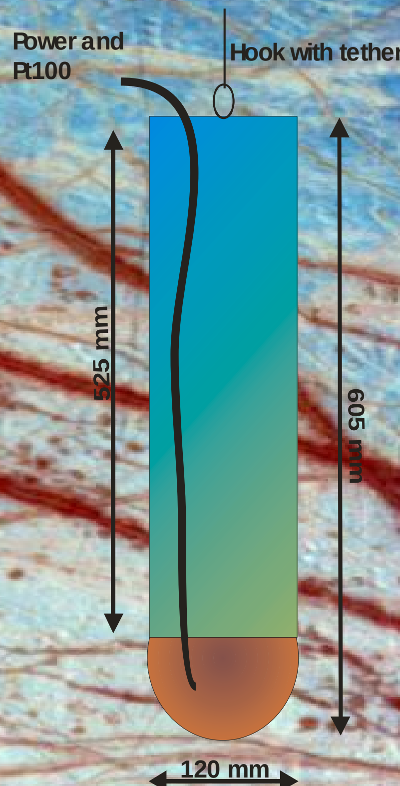
	CO_2	CO	CH_4	H_2O
T_f, melting temperature (~1 bar) (K)	216.6	68.1	90.7	273.1
c_p, specific heat capacity (kJ/kgK)	1.38	1.90	2.35	1.13
L, phase transition enthalpy (kJ/kg)	573.3 (sublimation)	29.9	58.6	333.4
ρ, density (kg/m^3)	1540	920	500	920
Penetration velocity relative to water ice, T_{ice}=1/2 T_f, losses regarded as equal	0.40	5.1	5.4	1

Experience with melting probes, typical construction

- AWI (Alfred-Wegener-Institute for Polar and Marine Research, Bremerhaven, Germany): Achieved easily 250m in antarctic shelf ice with a 10cm diameter, 180 cm long melting probe, 1000 W electrical heater externally fed (1000 V lines with telemetry multiplexed into the supply), internal umbilical spool.
- 1 m/h melting velocity. Important lesson learnt: mechanism for steering (keeping vertical) important!
- A 1000 m project failed because the umbilical spool procuced a short due to overheating
- Experiments at DLR in air (-30°C) and vacuum (100 K)

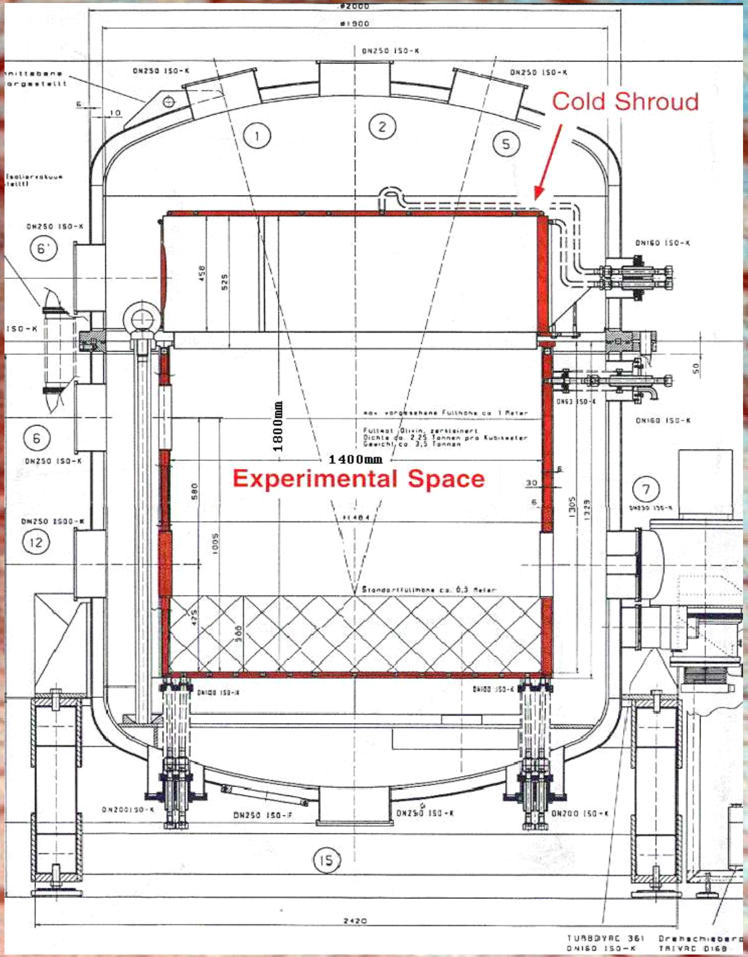
Setup of Test Probe



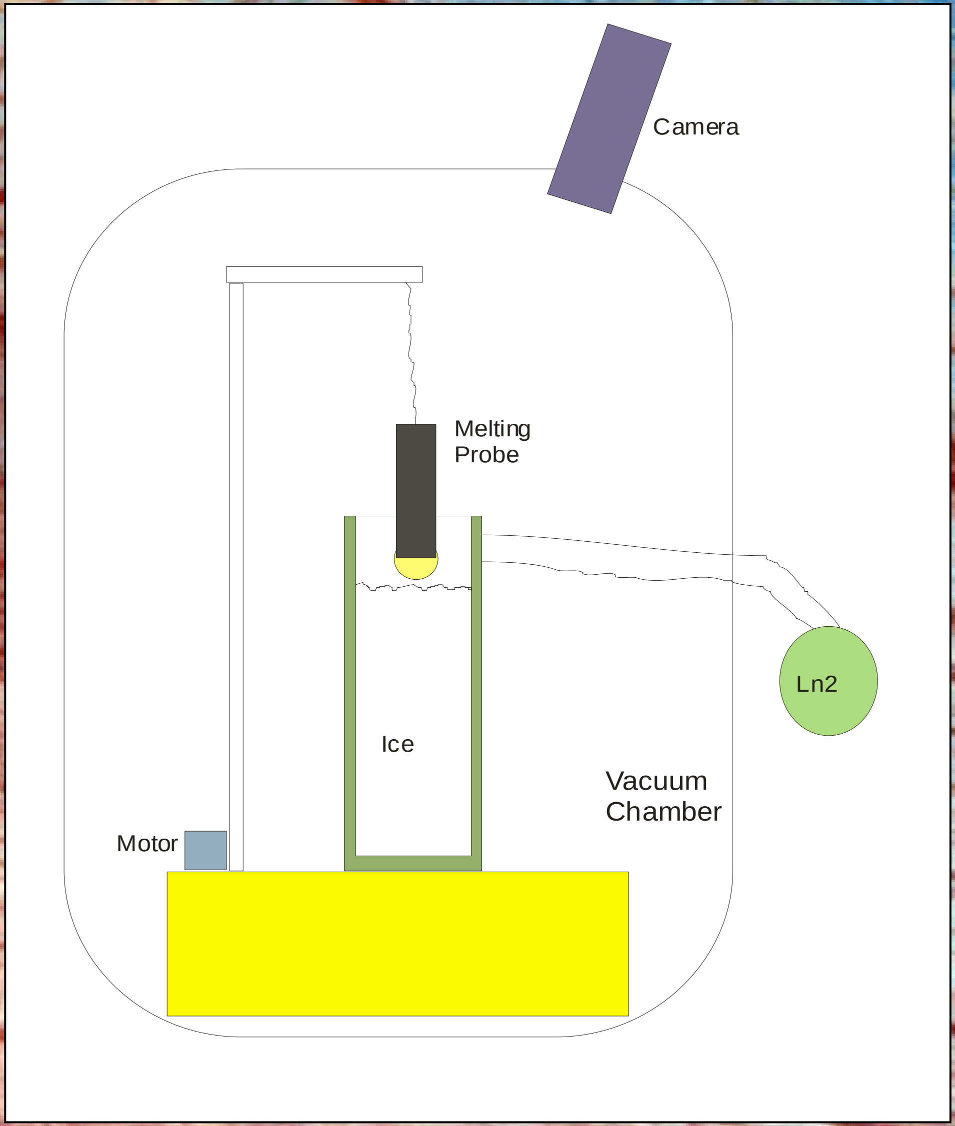


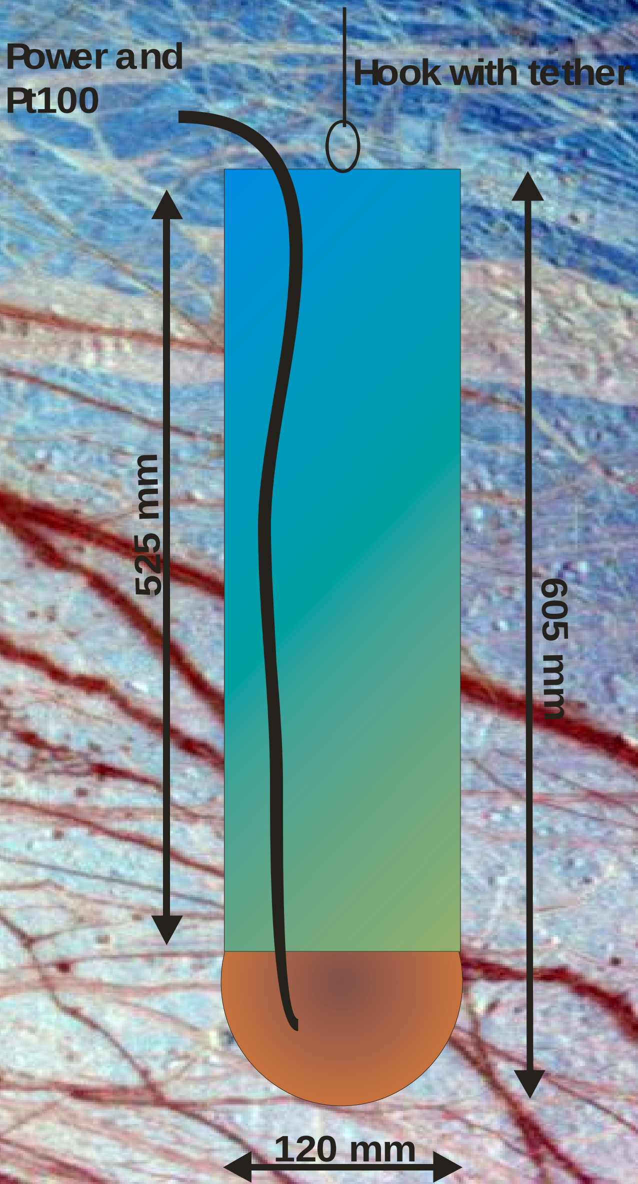
Heating power:
200 – 600 W

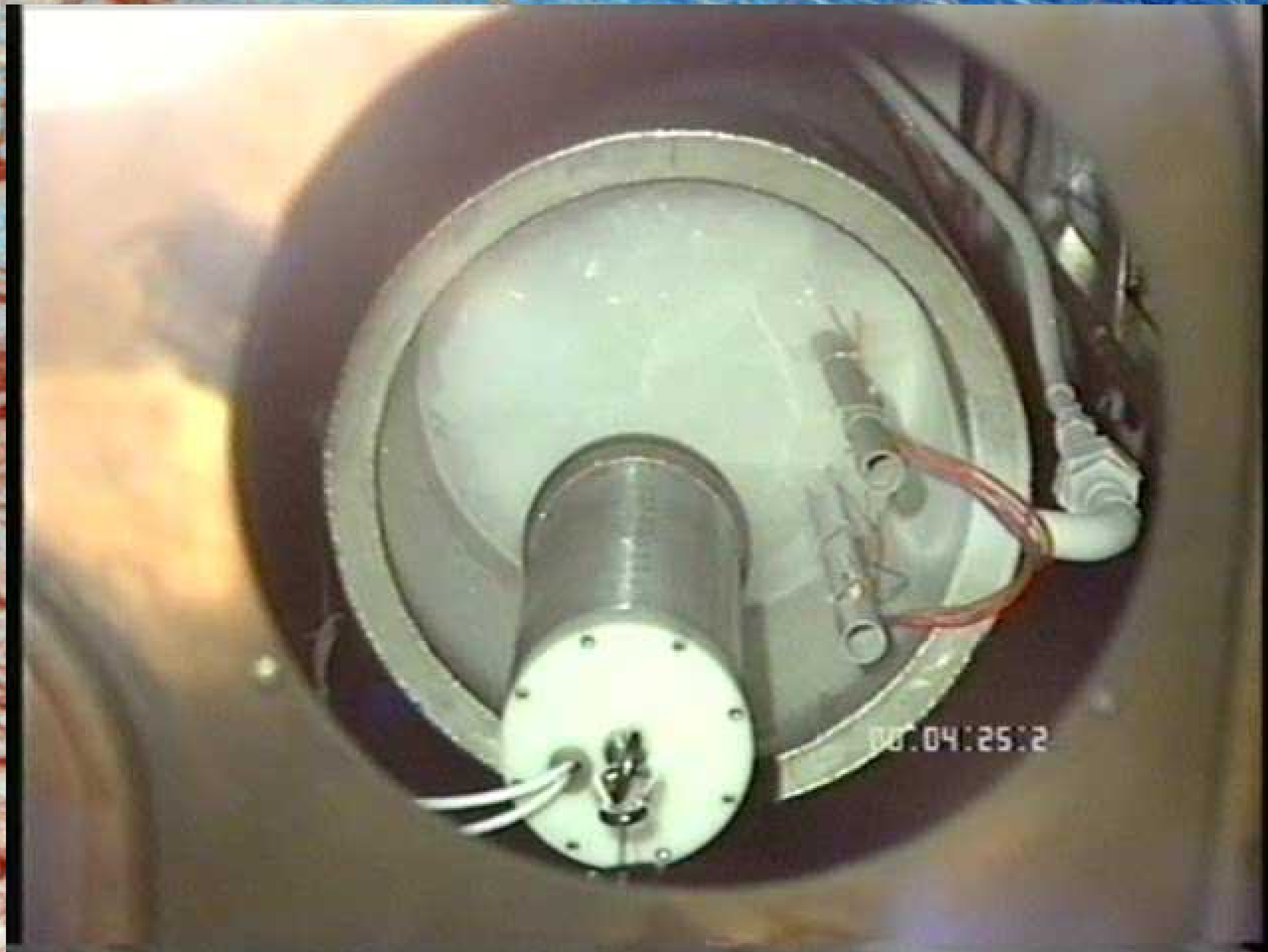
Vacuum Facilities



Experimental Setup







THEORY and PRAXIS: Conclusions from experiments

- Melting probe concept works in vacuum; sublimation or melting depending on local pressure, porosity, closure of channel
- Not just front-sphere, but whole probe needs to be heated if ice very cold
- Practical minimum power level exists
- Melting channel closes very rapidly (liquid water in cavity)

Obstacles, steering …

- Keeping probe vertical: solutions exist (tether clutch)
- Danger: accumulation of dust in front of melt head (→ mole mechanism [PLUTO], add. drillhead or water jet [NASA Cryobot]) - not really mature
- Danger: obstacles leading to tilt (→ steering by diff. Heating, mechanisms, …) - all not proven

Proposed Instrumentation

- **Control sensors** (temperatures, system attitude, signal strength for comms, etc.)
- **Habitat sensors** (conductivity, pH, t, electro-chemical spectra)
- **Optical sensors** (Refractive index sensor, Attenuated Total Reflection spectrometer (ATR), Cameras, UV Spectro-fluorometers, Raman spectrometers, Dissolved Oxygen chromophore systems)
- **Mass spectrometer** (MS) /chromotographic (C) input systems

Radioactive heating

- For planetary missions due to the high energy demand, only radioactive heating seems to be a feasible solution
- Traditional RHU technology is based on ^{238}Pu
- In case of Antarctica, ^{45}Ca seems to be an attractive alternative

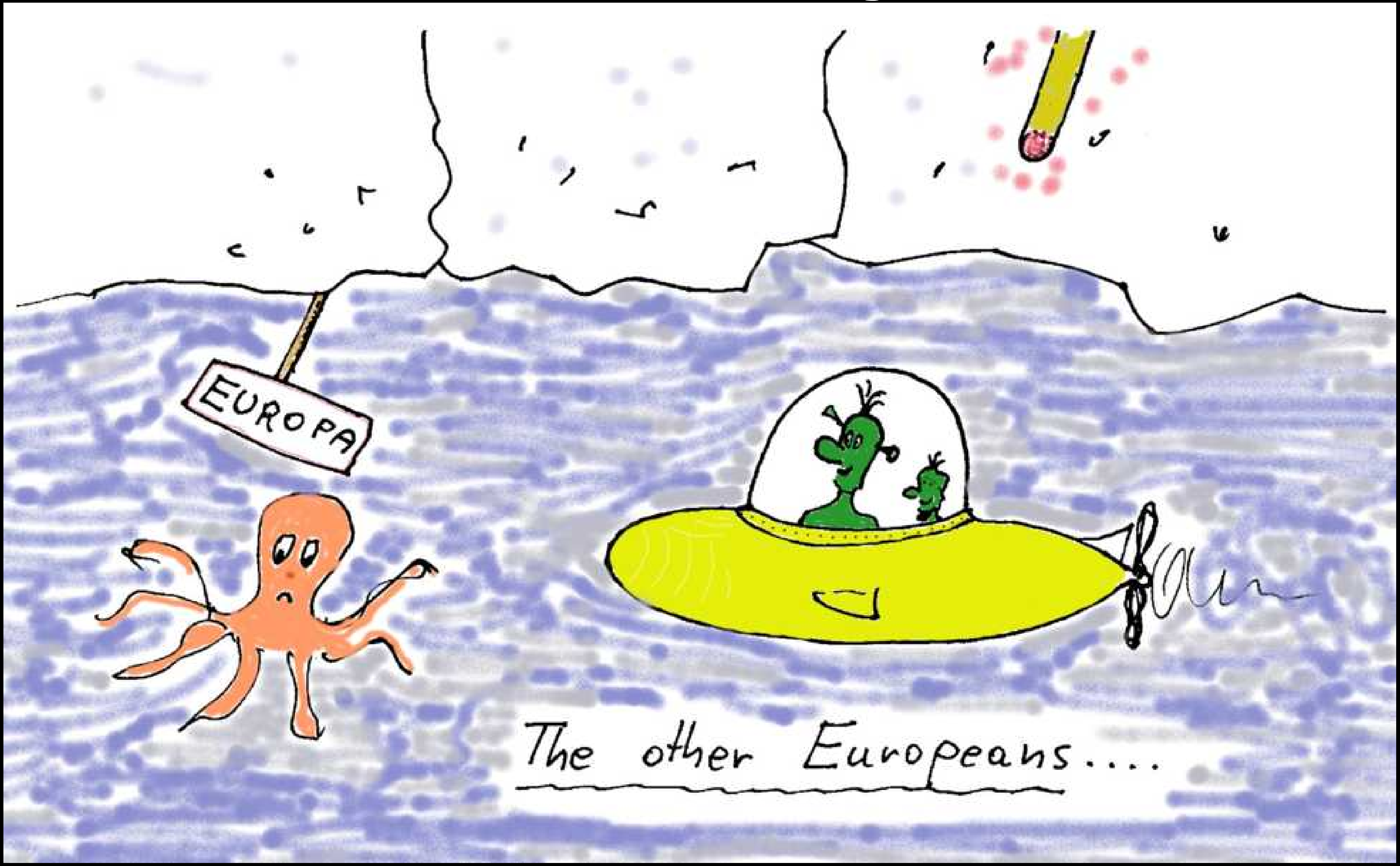
Communications

- For depths to about 1km, tether based power/comms between probe and surface may be considered 1
- For greater depths one possibility are ice transceivers (microwave repeaters, 2 cm x 10 cm, 120 mW transmit signal power, to relay 10 Kb/s over several 100 m in ice with 13 ppm salt impurities).
- Alternative (power with RTHs/RHUs not an issue): long wave technology, antenna coils instead of long $\lambda/4$ wires

Short range melting probe for a Europa Lander

- While the long-term goal is to penetrate thick ice crusts and explore the ocean beneath, in the short run (e.g., to equip a first Europa Lander) a simple melting probe to access the uppermost meters of Europa's crusts (where radiation levels are already low enough to permit the long term survival of organic matter) appears to be feasible.
- Variants with radioisotope and electrical heating and both sampling and in-situ probes are possible

Ultimatively…



Reference:

- **Stephan Ulamec, Jens Biele, Oliver Funke and Marc Engelhardt: Access to glacial and subglacial environments in the Solar System by melting probe technology, in Life in Extreme Environments**, Springer 2007, pp. 1-24